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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification:
H04B 10/04, G02B 6/10, H04B 10/16

A1

(11) International Publication Number: **WO 00/27054**

(43) International Publication Date: 11 May 2000 (11.05.2000)

(21) International Application Number: PCT/US99/25885

(22) International Filing Date: 04 November 1999 (04.11.1999)

(30) Priority Data:
09/185,820 04 November 1998 (04.11.1998) US

(60) Parent Application or Grant
CORVIS CORPORATION [/]; (). PRICE, Alistair, J. [/]; ().

Published

(54) Title: OPTICAL TRANSMISSION APPARATUSES, METHODS, AND SYSTEMS

(54) Titre: PROCÉDÉS, APPAREILS ET SYSTEMES DE TRANSMISSION OPTIQUE

(57) Abstract

Apparatuses, methods, and systems are disclosed that provide for simultaneously upconverting electrical signals (lambda sub e1, lambda sub en) carrying information at electric frequencies onto optical subcarrier lightwave frequencies (nu sub 0) that are greater and less than the carrier frequency of the lightwave onto which the electrical frequencies vere upconverted. The upconversion of the elctrical signals can be performed with or without suppression of the optical carrier frequency.

(57) Abrégé

L'invention concerne des procédés, des appareils et des systèmes permettant de transposer simultanément, par montée en fréquence, des signaux électriques ('lambda'e1, 'lambda'en) portant des informations de fréquence électrique, sur des fréquences ('nu'¿0) d'onde lumineuse de sous-porteuse optique supérieures ou inférieures à la fréquence de porteuse sur laquelle la montée en fréquence des signaux électriques peut s'effectuer. La montée en fréquence des signaux électriques peut s'effectuer avec ou sans suppression de la fréquence de porteuse optique.

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(22) International Filing Date: 4 November 1999 (04.11.99)

(30) Priority Data:
09/185,820 4 November 1998 (04.11.98) US

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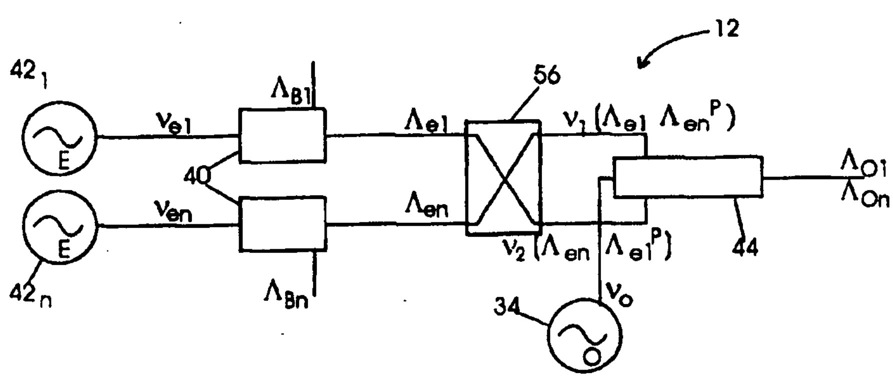
(81) Designated States: BR, CA, CN, IN, JP, MX, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: OPTICAL TRANSMISSION APPARATUSES, METHODS, AND SYSTEMS



(57) Abstract

Apparatuses, methods, and systems are disclosed that provide for simultaneously upconverting electrical signals (lambda sub e1, lambda sub en) carrying information at electric frequencies onto optical subcarrier lightwave frequencies (nu sub 0) that are greater and less than the carrier frequency of the lightwave onto which the electrical frequencies vere upconverted. The upconversion of the elctrical signals can be performed with or without suppression of the optical carrier frequency.

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Description

OPTICAL TRANSMISSION APPARATUSES, METHODS, AND SYSTEMS

FIELD OF THE INVENTION

The present invention is directed generally to the transmission of information in communication systems. More particularly, the invention relates to transmitting information via optical signals in optical transmission systems and transmitters for use therein. This application claims the benefit of U.S. Patent Application No. 09/185,820 filed November 4, 1998. This application also is related to commonly assigned U.S. patent application Serial Nos. 09/185,821 and 09/185,816, filed on November 4, 1998, which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The development of digital technology provided resources to store and process vast amounts of information. While this development greatly increased information processing capabilities, it was soon recognized that in order to make effective use of information resources, it was necessary to interconnect and allow communication between information resources. Efficient access to information resources requires the continued development of information transmission systems to facilitate the sharing of information between resources.

The continued advances in information storage and processing technology has fueled a corresponding advance in information transmission technology. Information transmission technology is directed toward providing high speed, high capacity connections between information resources. One effort to achieve higher transmission capacities has focused on the development of optical transmission systems for use in conjunction with high speed electronic transmission systems. Optical transmission systems employ optical fiber networks to provide high capacity, low error rate transmission of information over long distances at a relatively low cost.

The transmission of information over fiber optic networks is performed by imparting the information in some manner to a lightwave carrier by varying the characteristics of the lightwave. The lightwave is launched into the optical fiber in the network to a receiver at a destination for the information. At the receiver, a photodetector is used to detect the lightwave variations and convert the information carried by the variations into electrical form.

In most optical transmission systems, the information is imparted by using the information data stream to either modulate a lightwave source to produce a modulated lightwave or to modulate the lightwave after it is emitted from the light source. The former modulation technique is known as "direct modulation", whereas the latter is known as "external modulation", i.e., external to the lightwave source. External modulation is more often used for higher speed transmission systems, because the high speed direct modulation of a source often causes undesirable variations in the wavelength of the source. The wavelength variations, known as chirp, can result in transmission and detection errors in an optical system.

Data streams can be modulated onto the lightwave using a number of different schemes. The two most common schemes are return to zero (RZ) and non-return to zero (NRZ). In RZ modulation, the modulation of each bit of information begins and ends at the same modulation level, i.e., zero, as shown in Fig. 1a. In NRZ schemes, the modulation level is not returned to a base modulation level, i.e., zero, at the end of a bit, but is directly adjusted to a level necessary to modulate the next information bit as shown in Fig. 1b. Other modulation schemes, such as duobinary and PSK, encode the data in a waveform, such as in Fig. 1c, prior to modulation onto a carrier.

In many systems, the information data stream is modulated onto the lightwave at a carrier wavelength, λ_o, (Fig. 2a) to produce an optical signal carrying data at the carrier wavelength, similar to that shown in Fig. 2b. The

modulation of the carrier wavelength also produces symmetric lobes, or sidebands, that broaden the overall bandwidth of the optical signal. The bandwidth of an optical signal determines how closely spaced successive optical signals can be spaced within a range of wavelengths.

Alternatively, the information can be modulated onto a wavelength proximate to the carrier wavelength using subcarrier modulation ("SCM"). SCM techniques, such as those described in U.S. Patent Nos. 4,989,200, 5,432,632, and 5,596,436, generally produce a modulated optical signal in the form of two mirror image sidebands at wavelengths symmetrically disposed around the carrier wavelength (Fig. 2c). Generally, only one of the mirror images is required to carry the signal and the other image is a source of signal noise that also consumes wavelength bandwidth that would normally be available to carry information. Similarly, the carrier wavelength, which does not carry the information, can be a source of noise that interferes with the subcarrier signal. Modified SCM techniques have been developed to eliminate one of the mirror images and the carrier wavelength, such as described in U.S. Patent Nos. 5,101,450 and 5,301,058.

Initially, single wavelength lightwave carriers were spatially separated by placing each carrier on a different fiber to provide space division multiplexing ("SDM") of the information in optical systems. As the demand for capacity grew, increasing numbers of information data streams were spaced in time, or time division multiplexed ("TDM"), on the single wavelength carrier in the SDM system as a means to provide additional capacity. The continued growth in transmission capacity has spawned the transmission of multiple wavelength carriers on a single fiber using wavelength division multiplexing ("WDM"). In WDM systems, further increases in transmission capacity can be achieved not only by increasing the transmission rate of the information via each wavelength, but also by increasing the number of wavelengths, or channel count, in the system.

There are two general options for increasing the channel count in WDM systems. The first option is to widen the transmission bandwidth to add more channels at current channel spacings. The second option is to decrease the spacing between the channels to provide a greater number of channels within a given transmission bandwidth. The first option currently provides only limited benefit, because most optical systems use erbium doped fiber amplifiers ("EDFAs") to amplify the optical signal during transmission. EDFAs have a limited bandwidth of operation and suffer from non-linear amplifier characteristics within the bandwidth. Difficulties with the second option include controlling optical sources that are closely spaced to prevent interference from wavelength drift and nonlinear interactions between the signals.

A further difficulty in WDM systems is that chromatic dispersion, which results from differences in the speed at which different wavelengths travel in optical fiber, can also degrade the optical signal. Chromatic dispersion is generally controlled in a system using one or more of three techniques. One technique to offset the dispersion of the different wavelengths in the transmission fiber through the use of optical components such as Bragg gratings or arrayed waveguides that vary the relative optical paths of the wavelengths. Another technique is intersperse different types of fibers that have opposite dispersion characteristics to that of the transmission fiber. A third technique is to attempt to offset the dispersion by prechirping the frequency or modulating the phase of the laser or lightwave in addition to modulating the data onto the lightwave. For example, see U.S. Patent Nos. 5,555,118, 5,778,128, 5,781,673 or 5,787,211. These techniques require that additional components be added to the system and/or the use of specialty optical fiber that has to be specifically tailored to each length of transmission fiber in the system.

New fiber designs have been developed that substantially reduce the chromatic dispersion of WDM signals during transmission in the 1550 nm wavelength range.

However, the decreased dispersion of the optical signal allows for increased nonlinear interaction, such as four wave mixing, to occur between the wavelengths that increases signal degradation. The effect of lower dispersion on nonlinear signal degradation becomes more pronounced at increased bit transmission rates.

The many difficulties associated with increasing the number of wavelength channels in WDM systems, as well as increasing the transmission bit rate have slowed the continued advance in communications transmission capacity. In view of these difficulties, there is a clear need for transmission techniques and systems that provide for higher capacity, longer distance optical communication systems.

BRIEF SUMMARY OF THE INVENTION

Apparatuses and methods of the present invention address the above need by providing optical communication systems that include transmitters that can provide for pluralities of information carrying wavelengths per optical transmission source, dispersion compensation, and/or nonlinear management in the system. In an embodiment, the information data stream is electrically distorted to compensate for chromatic dispersion of a lightwave/optical signal during transmission. The electrical distortion can be used to compensate for negative or positive dispersion in varying amounts depending upon the characteristics of the optical fiber in the network and to some extent offset nonlinear interactions that produce distortion of the optical signal. Electrical distortion can be specifically tailored to each wavelength and bit rate used in the optical system.

Electrical dispersion compensation can be used in conjunction with other methods, such as dispersion compensating fiber or time delay components to control the level of dispersion at various points in the network. The amount of dispersion in the system can be controlled to provide a substantially predetermined value of net dispersion, e.g., zero, at the end of a link, to provide an

average value over the link, and/or to minimize the absolute dispersion at any point in the link.

Electrical distortion compensation can be used with RZ, NRZ, ASK, FSK, PSK, and duobinary formats, as well as other modulation formats and baseband and subcarrier modulation techniques. In addition, the amount of electronic distortion applied to a signal can be controlled via a feedback loop from a receiver in the system to allow fine tuning of the compensation. In this manner, changes in the network performance with time can be accommodated.

In an embodiment, an information data stream is modulated on to an electrical carrier, such radio frequency ("RF") or microwave carrier, frequency ν_e. The modulated electrical carrier is upconverted on to a lightwave carrier having a wavelength λ_0 and frequency ν_0 produced by the optical transmission source to produce an information carrying lightwave at wavelength λ_1 and frequency ν_{0+e}. The upconverter can be used to simultaneously upconvert a plurality of electrical frequencies onto different subcarrier lightwaves. In an embodiment, the information is modulated onto the electrical carrier in duobinary format, which provides for more narrow subcarrier bandwidths.

In an embodiment, the lightwave carrier from the optical source is split into a plurality of split lightwave carriers, each of which has one or more data streams upconverted or modulated onto it. The subcarrier lightwave optical signals generated from the split lightwave optical carriers are then recombined into the optical signal for transmission. The split lightwave carrier overcomes the problem of maintaining close wavelength spacing between multiple carriers in an operating system by employing a common optical source. The optical source providing the lightwave carrier may include one or more lasers or other optical sources.

The split lightwave carrier also provides a method of placing multiple information carrying wavelengths near the lightwave carrier without having to upconvert or modulate

more than one data stream at a time onto a lightwave carrier. The upconverted lightwaves can be at wavelengths that are greater and/or less than the carrier wavelength and symmetrically or asymmetrically positioned relative to the carrier wavelength. In addition, subcarriers can be simultaneously upconverted onto the same lightwave, at least one subcarrier with a higher frequency and at least one subcarrier with a lower frequency than the carrier frequency.

The upconversion of the modulated electrical carrier can be performed using double or single sideband upconverters with or without suppression of the carrier wavelength λ_o. However, the reduction or elimination of the carrier wavelength λ_o and any mirror image sideband will eliminate unwanted signals that could interfere with the upconverted signal.

In an embodiment, a two sided, single sideband upconverter is provided to modulate multiple information data streams onto both longer and shorter wavelengths. In those embodiments, one upconverter can be used to upconvert data on equally or differently spaced subcarriers relative to the carrier wavelength.

In an embodiment, the polarization of adjacent lightwave carriers is controlled to decrease the nonlinear interactions of the signals. For example, adjacent wavelength signal can be orthogonally polarized to decrease the extent of four wave mixing that occurs between the signals during transmission. In addition, the wavelength spacing between neighboring upconverted signals can be selected to lessen non-linear interaction effects.

Accordingly, the present invention addresses the aforementioned problems with providing increasing the number of channels and the transmission performance of optical systems. These advantages and others will become apparent from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings wherein like members bear like reference numerals and wherein:

Figs. 1a-c show a typical baseband return to zero ("RZ") and non-return to zero ("NRZ") data signal;

Figs. 2a-c show the intensity versus wavelength plots for an unmodulated optical carrier, modulated carrier, and modulated subcarriers of the carrier;

Figs. 3-4 show embodiments of the system of the present invention; and,

Figs. 5 shows an embodiment of a transmitter of the present invention;

Fig. 6a&b show transmission & reception time versus wavelength curves;

Figs. 7a-c show embodiments of signal distorters of the present invention

Figs. 8-11 show embodiments of transmitters of the present invention

Fig. 12 shows an embodiment of transmitters of the invention;

Fig. 13 shows an embodiment of upconverters of the present invention;

Figs. 14-16 show embodiments of transmitters of the present invention; and,

Fig. 17 shows a polarizing element of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The operation of optical systems 10 of the present invention will be described generally with reference to the drawings for the purpose of illustrating present embodiments only and not for purposes of limiting the same. As shown in Fig. 3, the system 10 includes an optical transmitter 12 configured to transmit information, i.e., data, etc., via one or more information carrying optical wavelengths λ_i to an optical receiver 14 through one or more segments of optical fiber 16_j. The system 10 may also include one or more dispersion compensating components 18 and feedback controllers 20, as well as other optical components such as optical amplifiers 22, add/drop devices 24, and the like.

As shown in Fig. 4, the system 10 can be embodied as a network including a plurality of transmitters 12 and receivers 14 in optical communication through one or more optical switches 26, combiners 28, and/or distributors 30. For example, optical and digital cross connect switches and routers, multiplexers, splitters, and demultiplexers can be employed in the system 10. The transmitters 12 and receivers 14 can interface directly with electrical transmission systems or via electrical switches or interfaces to other optical systems that operate using the same or different wavelengths.

In an embodiment, the transmitter 12 is configured to electrically distort an electrical signal carrying data to compensate for chromatic dispersion that occurs as an optical signal Λ_o carrying the data is transmitted through the optical fiber 16_i. The electronic data signal Λ_E can be in a baseband Λ_B (i.e., binary, direct current), coded Λ_C, or a modulated electrical carrier Λ_e format.

In an embodiment of the transmitter 12 shown in Fig. 5, an electronic signal distorter 32 is configured to produce a distorted electrical signal Λ_{ED}. A distorted optical signal Λ_{OD} is produced using an electrical to optical converter 33 to impart the the electrical signal Λ_{ED} onto an optical

carrier lightwave Λ_O. The electrical to optical conversion can be performed by upconverting the electrical signal Λ_{ED} onto a subcarrier lightwave of an optical carrier lightwave Λ_O provided by an optical source 34. Alternatively, the conversion of electrical signal Λ_{ED} can be performed by directly modulating the optical source 34 or externally modulating the optical carrier lightwave Λ_O to produce the optical data signal at the carrier frequency. One or more signal lasers, or other appropriate optical sources as may be known in the art, can be used as the optical source 34.

The distortion of the electronic data signal is generally in the form of an electronically induced time delay that varies as a function of the optical wavelength λ_i in the optical signal Λ_O. The group delay can be used to provide varying amounts of dispersion compensation for each wavelength and for each bit rate in the system 10. The time delay characteristics can be controlled to provide linear and nonlinear, as well as positive, negative, and varying, delay profiles with respect to the wavelength of the signal.

Fig. 6a shows an example of a typical relative time delay at the receiver versus wavelength plot for an optical signal being transmitted with zero dispersion at a transmission time t_t. Dispersion of the signal during transmission results in the different wavelengths in the signal reaching the receiver 14 at different times during a reception time interval, Δt_r. The time delay in signal reception is one source of signal distortion that degrades system performance. In the present invention, distorted optical signals can be produced by introducing distortion as a group delay function of frequency, which results in the signal being transmitted over a transmission time interval Δt_t. The electronic distortion is offset by dispersion in the transmission path resulting in the different frequencies reaching the receiver 14 at the same reception time t_r (Fig. 6b), or over a reception time interval of choice (Fig. 6c).

One skilled in the art will appreciate that in the present invention the distortion profile of the electronic data signal can be varied as desired to control the shape of optical signal at the receiver 14. For example, given the interrelation of chromatic dispersion and nonlinear interactions, the electrical distortion characteristics can be shaped to minimize the total distortion at the receiver 14 as opposed to minimizing only the chromatic dispersion. In addition, electronic dispersion compensation can be used in conjunction with dispersion compensating elements 18, such as negative dispersion slope fiber, grating-based elements, etc. as are known in the art.

Figs. 7a-c show embodiments of signal distorter 32 of the present invention. In Fig. 7a, the distorter 32 includes one or more serial electrical circulators 36 having an input to an input port 1 that circulates the electrical signal to an equalizer port 2. A resonator 38 can be connected to port 2 to serve as an all-pass transmission filter that reflects all incident power in a frequency dependent manner back to the port 2, thereby distorting signal. The distorted electrical signal Λ_{ED} exits an output port 3 of the circulator 36 from which it can be passed into another distortion element or exit the signal distorter 32.

An example of resonators 38 that are suitable for use in the present invention are impedance resonators following the general equation:

$$Z(s) = sL + 1/(sC)$$

$$L = RQ/(2\pi f_0)$$

$$C = 1/(4\pi^2 f_0^2 L)$$

$$H(s) = (Z(s)-R)/(Z(s)+R)$$

$$D(\omega) = -d/d\omega(\arg(H(j\omega))),$$ where

Z = impedance	C = capacitance	$D(\omega)$ = group delay
L = inductance	f_0 = frequency	H(s) = equalizer Transfer function
R = resistance	Q = Q factor	

One skilled in the art will appreciate that the circulator/resonator embodiments shown in Fig. 7a can be cascaded to provide desired group delay characteristics and that other networks may be used in the present invention. For example, in Fig. 7b, the signal distorter 32 includes one or more electrical loop couplers 35 configured to introduce the desired group delay into the electical carrier signal Λ_e. Various configurations of loop couplers suitable to achieve the desired group delay can be used in the distorter 32. Fig. 7c shows an embodiment of the signal distorter 32 for distorting the baseband signal Λ_B. The distorter 32 is used to separate the baseband signal Λ_B into I and Q components by configuring the inductors 37 and capacitors 39 to approximate the following general transfer function over the frequency range of interest:

$$|H_I(j\omega)|^2 + |H_Q(j\omega)|^2 = \text{constant}.$$

The amount of dispersion in optical fiber 16_i is generally well documented as a function of fiber length and optical wavelength. For example, transmission fiber can typically be in the range of 15-20 ps/nm/km in the 1550 nm wavelength range. Thus, the amount of distortion necessary to produce a desired dispersion profile at a point in the optical transmission system can be calculated and adjusted as may be necessary in the system 10. In addition, the shape of the distortion profile can be tailored to be linear or nonlinear functions of frequency to compensate for the interrelation of chromatic dispersion and nonlinear interactions.

Fig. 8 shows an embodiment of the transmitter 12 in which an electrical modulator 40 is used to modulate the baseband electric signal Λ_B onto an electrical carrier at a frequency ν_e from an electrical carrier source 42. The modulator 40 can be a double balanced mixer as is known in the art. The electrical carrier signal ν_e will be of the general form $A(\sin(\omega+\phi)$ and the baseband signal Λ_B of the form V(t) resulting in an output signal of the general form

$kV(t)A(\sin(\omega+\phi+\phi_i)$. Thus, if the mean of the baseband signal is zero, the carrier frequency will be suppressed. Likewise, if V(t) has essentially two state $\pm a$, the output will be in PSK format.

The electrical carrier frequency can be any suitable frequency for the data rate being transmitted, for example, RF or microwave carriers. The signal distorter 32 receives the modulated electrical carrier signal Λ_e at frequency v_e and provides the distorted electrical carrier signal Λ_{eD}. An upconverter 44 combines the distorted modulated electrical carrier at v_e with an optical lightwave carrier at a central wavelength λ_o (frequency v_o) supplied by an optical source 34. The resulting distorted optical signal Λ_{OD} has a frequency $v_o \pm v_e$ ("$v_{o\pm e}$") and central wavelength at $\lambda_{o\pm e}$, which is equal to $c/(v_o \pm v_e)$, where c is the speed of light.

In embodiments shown in Figs. 8b and 9, the baseband electrical signal Λ_B is provided to the signal distorter 32, which is configured to separate the signal Λ_B into in-phase ("I") and quadrature ("Q") components and distort the signal. The IQ components of the distorted electrical signal Λ_{BD} are provided to an IQ modulator 46. In the Fig. 8b embodiments, the I and Q components are modulated onto the electrical carrier v_e which is upconverted onto the optical carrier v_o to produce the distorted optical signal Λ_{OD} at the central wavelength at $\lambda_{o\pm e}$. In Fig. 9 embodiments, the I and Q components are modulated onto the optical carrier having a central wavelength λ_o and frequency v_o to provide the distorted optical signal Λ_{OD} having the same central wavelength at λ_o.

Conversely in Fig. 10, the baseband signal Λ_B is modulated onto a portion of the electrical carrier v_e, which is passed through the signal distorter 32 to produce the distorted electrical signal Λ_{eD}. Another portion of the

electrical carrier ν_e is provided as input along with the distorted electrical signal Λ_{eD} to an IQ demodulator 48, which separates the distorted electrical signal Λ_{eD} into its IQ components. The IQ components of the electronic signal are provided to the IQ modulator 46 which modulates the data onto the optical carrier at the central wavelength λ_o and frequency ν_o provided by the optical source 34.

In the transmitter 12 of Fig. 11, the electrical baseband signal Λ_B can be encoded along with a clock signal Λ_{CLK} using a data encoder 50 to provide an encoded data signal Λ_C. The encoded data signal Λ_C may be further passed through a filter 52, such as a low pass filter, to shape the signal before being passed to the signal distorter 32. In the transmitter 12 of Fig. 11, the IQ modulator 46 can be used to modulate the distorted electrical signal onto the electrical carrier frequency ν_e. The electrical carrier can be amplified using an electrical amplifier 54, split through electrical coupler 56, and upconverted onto the optical carrier to produce the distorted optical signal Λ_{OD} having its center wavelength at $\lambda_{o\pm e}$. One of the controllers 20 in the system 10 can be used to provide feedback control of the upconverter 44, as well as the other components such as the amplifier 54.

In embodiments of Fig. 11, the electrical coupler 56 is used to split the signal from each input path between two output paths and impart a phase shift, i.e. 90° in a 2x2 3dB coupler, between signals on the respective output paths. The phase shift between the two output paths depends upon which input path the signal was introduced. Thus, the frequency of the resulting distorted optical signal Λ_{OD} will be either $\nu_{o+e} = \nu_o + \nu_e$ or $\nu_{o-e} = \nu_o - \nu_e$ depending upon which input of the coupler 56 the electrical signals are introduced.

Data encoding techniques, such as duobinary, QPSK, and others, are useful to decrease the bandwidth of the resulting optical signal. These formats can also affect the

extent of distortions that arise from signal dispersion and non-linear interaction between the signals. The detection of duobinary and other differential PSK-type signals using direct detection can be enhanced using an optical filter 58 before the receiver 14 in the optical system 10. The optical filter 58 can be matched, i.e., comparably shaped, to the received optical spectrum of the signal, which can be controlled in the present invention using the electrical filter 52. The optical filter 58 can be a Fabry-Perot filter or other appropriate filter as may be known in the art. The electrical filter 52 can be design to account for and match the properties of the optical filter 58 so as to minimize the bandwidth of the optical signal. It will be appreciated that the electrical filter 52 can be positioned at different locations within the transmitter 12 and modified accordingly.

In another aspect of the invention shown in Fig. 12, the transmitter 12 of the present invention can be used to simultaneously upconvert a plurality of electrical signals Λ_{Bn} onto one optical carrier. A plurality of baseband electrical signals Λ_{B1}-Λ_{Bn} are modulated onto a corresponding plurality on electrical carriers provided by sources 42_1-42_n to provide modulated electrical carriers. Signal distorters 32 can be provided to distort either the baseband signal or the modulated electrical carrier, if dispersion compensation is desired. The modulated electrical carriers are passed through the electrical coupler 56, which divides the electrical signals between the two output paths leading to the upconverter 44.

Numerous combinations of electrical carriers can be upconverted using the transmitter configuration of Fig. 12. For example, electrical sources 42_1 through 42_n can provide the same or different electrical carrier frequencies and depending upon how the carriers are coupled into the upconverter 44. If more than two electrical carriers are to be upconverted using the same upconverter 44, the additional carriers can be combined, or multiplexed, onto the

appropriate coupler input. The resulting optical signal can be produced at longer or shorter wavelengths than the optical carrier wavelength λ_o as previously discussed. In addition, it may also be possible to use one or more electrical subcarriers to carry additional data along with, or in lieu of, data on the electrical carrier frequency depending upon the electrical subcarrier frequency spacings.

The upconverter 44 in embodiments of Figs. 12 and 13 is configured to upconvert the electrical signal onto a single sideband subcarrier frequency, either ν_{o+e} or ν_{o-e}, while suppressing the mirror image sideband subcarrier frequency. The upconverter can be operated without or with carrier wavelength suppression, although carrier suppression eliminates unwanted signals that could produce signal interference.

Fig. 14 shows an embodiment of the single side band suppressed carrier upconverter 44 suitable for use in the present invention. Other suitable single side band embodiments include those described by Olshansky in U.S. Patent Nos. 5,101,450 and 5,301,058, which are incorporated herein by reference. As shown in Fig. 14, the optical carrier lightwave at frequency ν_o is split using an optical splitter 60 into two respective optical paths, 62_1 and 62_2, which are further split into optical paths $62_{1'}$ and $62_{1''}$. The split lightwaves in optical paths 62_1 are passed between first upconverter input electrode 64_1 and a pair of ground electrodes 66. Likewise, the split lightwaves in optical paths 62_2 are passed between second upconverter input electrode 64_2 and a pair of ground electrodes 66. Electrical input signals v_1 and v_2 are provided to the upconverter respective input electrodes 64_1 and 64_2 via first and second inputs, 68_1 and 68_2, respectively. The input signals v_1 and v_2 are upconverted onto the respective split lightwaves passing between the electrodes and combined in cascaded optical combiners 70 to produce the upconverted optical signal Λ_o.

In an embodiment, $LiNbO_3$ is used to form the optical paths $62_{i'}$ and $62_{i''}$, which can be used to produce linearly polarized optical signals. In addition, bias electrodes can be provided in optical paths $62_{i'}$ and $62_{i''}$ and/or 62_i after passing through the input electrodes 64_1 and 64_2. The bias electrodes can be used to trim the phase difference of the optical signals upconverted onto the subcarrier lightwaves in each path before the signals are combined.

The electrical input signals v_1 and v_2 introduced to the upconverter 44 carrying the same electrical data signal, except that the data signals have a relative phase shift between the first and second inputs, 68_1 and 68_2, according to the relation: $v_1 = v_2 \pm$ phase shift. The sign of the phase shift determines whether the electrical data signal will be upconverted onto lightwave subcarriers that are greater or less than the carrier frequency of the lightwave. Thus, the upconverter 44 can be configured to receive and simultaneously upconvert electrical signals at the same or different electrical frequencies onto different subcarrier lightwave frequencies of the same lightwave by introducing the appropriate phase shift between the electrical input signals. For example, in embodiments of Figs. 12 and 13, 3 dB electrical couplers 56 provide a $\pm$ 90° phase shift, which allows electrical signals to be upconverted onto optical frequencies that are greater or less than the carrier frequency. One skilled in the art will appreciate that other techniques for imparting the phase shift are suitable within the scope of the invention.

The transmitter 12 shown Fig. 13 provides a configuration that can be used to symmetrically place two different optical signals around the central wavelength λ_o of the optical carrier. The electrical carrier 42 supplies the electrical carrier v_e that is split into two paths, each of which is modulated using a corresponding modulator 36_1 or 36_2 with electrical baseband signals Λ_{B1} and Λ_{B2}, respectively. The two signals are passed through the electrical coupler 56 which splits and couples the signals

from each of the two coupler input paths to each of the two output paths. The coupler 56 introduces a 90° phase shift into the coupled portion of the signal, shown as Λ_{e1}^{P} and Λ_{e2}^{P} on Figs. 12 and 13, to produce upconverter input signals v_1 and v_2. For example in Fig. 13, v_1 includes Λ_{e1}^{P} and Λ_{e2}, whereas v_2 includes Λ_{e1}, and Λ_{e2}^{P}. The opposite phase shifts of v_1 and v_2 results in one of the two electrical signals being upconverted onto an optical subcarrier frequency ν_{o+e}. The other electrical signal is upconverted onto the optical subcarrier frequency ν_{o-e}, symmetric to the optical carrier frequency ν_o. A skilled artisan will recognize that distorted and undistorted optical signals can be produced using the embodiment of Fig. 13 and similar embodiments.

An embodiment of the transmitter 12, shown in Fig. 15, can be also used to provide control over proximate optical wavelengths by upconverting one or more electrical frequencies onto a plurality of optical carriers provided by the common optical source 34. The optical carrier lightwave is split using the optical splitter 60 into split lightwaves carried on a plurality of optical paths 62_1 - 62_n. A corresponding plurality of the upconverters 44_{1-n} are disposed along the optical paths. A plurality of electrical baseband signal Λ_{B1}-Λ_{Bn} are correspondingly modulated onto electrical carrier ν_{e1}-ν_{en} via modulators 40_{1-n}. The electrical carrier signals Λ_{e1}-Λ_{en} are provided to the upconverters 44_{1-n} and converted to subcarrier lightwave optical signals Λ_{o1}-Λ_{on} at frequencies ν_{oe1}-ν_{oen} and combined using an optical combiner or multiplexer 68. When only one electrical signal is upconverted onto a split lightwave optical carrier in a path 62_i, single or double sideband upconverters, with or without carrier suppression, can be used in the invention. Optical filters 58 can be employed to remove any undesired remnant carrier wavelengths or mirror image sidebands that are output from the particular modulator used in the transmitter 12.

Fig. 16 shows an embodiment of the transmitter 12 that is configured to transmit four optical signals using a single optical source 34, such as a laser 72, emitting the optical carrier at a central wavelength λ_o and frequency v_o. The baseband electrical signal Λ_{B1}-Λ_{B4} are provided as input to corresponding data encoders $50_{1\text{-}4}$ from an electrical transmission path or from the optical receiver 14 in a short or long reach optical system. The encoded electrical signal is passed through the shaping filter $52_{1\text{-}4}$ to respective electrical modulators 40. Encoded electrical signals Λ_{C1}-Λ_{C2} and Λ_{C3}-Λ_{C4} are modulated onto the electrical carrier at frequency v_{e1} and v_{e2}, respectively. The modulated electrical signals Λ_{e11}-Λ_{e24} are passed through respective signal distorters $32_{1\text{-}4}$ and electrical amplifiers $54_{1\text{-}4}$ to provide amplified distorted electrical signals Λ_{e11D}-Λ_{e24D}. Electrical signals Λ_{e11D} and Λ_{e23D} can be routed through electrical coupler 56_1 to upconverter 44_1. Likewise, electrical signals Λ_{e12D} and Λ_{e24D} can be routed through electrical coupler 54_2 to upconverter 44_2. The upconverted optical signals Λ_{oe1D}-Λ_{oe4D} are combined in the combiner 62 prior to transmission. The interleaving of the electrical frequencies being upconverted allows for the use of optical filters 58, with either single or double sideband modulators, to remove any unwanted sidebands or carrier wavelengths from the optical signals Λ_{oe1D}-Λ_{oe4D}. Transmitters 12 of the present invention can also be used to modulate data onto the lightwave carrier wavelength, in addition to upconverting electrical frequency onto the lightwave.

In the present invention, transmitters 12 configured to provide multiple optical signals, can be further configured to impart opposite polarization to pairs of optical signals being generated by upconverting the electrical signals. For example, the optical combiner 62 in embodiments such as those shown in Figs. 15 and 16 can be a polarizing

component, such as a polarizing beam splitter/combiner. The orthogonal polarization of adjacent signals will reduce or eliminate nonlinear interaction between the signals, thereby providing for more closely spaced signal wavelengths and high power signals.

Alternatively, as shown in Fig. 17, a separate polarizing element 74 can be included in the combiner 62. An embodiment of the polarizing element 74 can includes two oppositely configured polarizing beam splitters 76 connected in series by two parallel paths 78 that produce a differential travel time between the splitters 76. The first beam splitter 76 splits the optical signal into two equal amplitude polarization components. The second beam splitter 76 is used to recombine the two polarization components. The time differential introduced by the parallel paths 78 can be established and/or controlled to introduce differences in the polarization of the channels. For example, optical signals having sufficiently narrow bandwidths can be introduced to the first beam splitter 76 at a 45° polarization angle to allow optical signal power to propagate equally in both paths 78. The resulting combined signals emerging from the second splitter 76 would be orthogonal if the time differential were equal to 1/(2*frequency difference between the signals). Similarly, polarization maintaining fiber can be used in lieu of the splitters 76 and parallel path 78 to introduce the time differential between the polarization components of a linearly polarized optical signal.

It will be appreciated that the present invention provides for optical systems having increasing the number of channels and the transmission performance of optical systems. Those of ordinary skill in the art will further appreciate that numerous modifications and variations that can be made to specific aspects of the present invention without departing from the scope of the present invention. It is intended that the foregoing specification and the following claims cover such modifications and variations.

Claims

CLAIMS

What is claimed is:

1. An apparatus comprising:

an upconverter having a first upconverter input and a second upconverter input, each input being configured to receive first and second electrical data signals, wherein the first electrical data signal on the second upconverter input has a first phase shift from the first electrical data signal on said first upconverter input and the second electrical data signal on the first upconverter input has a second phase shift relative to the second data signal on the second upconverter input opposite to the first phase shift such that said upconverter upconverts the first and second electrical data signals onto corresponding first and second subcarrier frequencies of a lightwave having a carrier frequency and at least one of the corresponding subcarrier frequencies is greater than the carrier frequency and at least one of the corresponding subcarrier frequencies is less than the carrier frequency.

2. The apparatus of claim 1, wherein said upconverter is further configured to suppress signals at the carrier frequency and corresponding mirror image subcarrier frequencies of the lightwave.

3. The apparatus of claim 1, wherein said upconverter includes an electrical coupler having a first output electrically connected to said first upconverter input and a second output electrically connected to said second upconverter input, said coupler being configured to receive the at least first and second electrical data signals and introduce the first phase shift to the first electrical signal and the second phase shift to the second electrical signal.

4. The apparatus of claim 3, wherein said electrical coupler has a first coupler input for receiving a first electrical data signal at a first electrical frequency and a second coupler input for receiving a second electrical data signal at a second electrical frequency.

5. The apparatus of claim 4, wherein said electrical coupler includes a 2x2 3 dB coupler.

6. The apparatus of claim 5, wherein the first electrical frequency is equal to the second electrical frequency; and,

said first upconverter input receives a portion of the first and second electrical signals that are 90° out of phase with the first and second electrical signals received by the second upconverter input.

7. A method of upconverting a plurality of electrical signals onto a lightwave comprising:

providing an upconverter configured to upconvert a first electrical signal including at least one electrical frequency carrying information provided to a first upconverter input to a corresponding at least one optical subcarrier frequency greater than a carrier frequency and a second electrical signal including at least one electrical frequency carrying information to a corresponding at least one optical subcarrier frequency less than the carrier frequency;

providing first and second electrical signals to the upconverter; and,

upconverting the first electrical signals onto subcarrier frequencies greater than the carrier frequency and the second electrical signals onto subcarrier frequencies less than the carrier frequency.

8. The method of claim 7, wherein:

said providing an upconverter includes providing an upconverter having first upconverter input and second upconverter input and configured to upconvert a plurality of electrical signals onto subcarrier frequencies of a lightwave at the carrier frequency, wherein each electrical signal is split between the first and second upconverter inputs and a first phase shift is introduced between the electrical signals provided to the first upconverter input and the second upconverter input;

said providing first and second electrical signal includes providing a plurality of electrical signals to both the first and second upconverter inputs, each electrical signal provided to the first upconverter input having the first phase shift relative to the second upconverter input, and

introducing a second phase shift opposite to the first phase to at least one of the plurality of electrical signals sufficient to provide for the at least one second phase shifted electrical signals to be upconverted to optical subcarrier frequencies that are less than a carrier frequency, when the first phase shifted electrical signal are upconverted to subcarrier frequencies greater than the carrier frequency and optical subcarrier frequencies that are greater than the carrier frequency, when the first phase shifted electrical signal are upconverted to subcarrier frequencies less than the carrier frequency; and,

said upconverting includes upconverting the plurality of electrical signals onto subcarrier frequencies of the lightwave.

9. The method of claim 7, wherein said providing an uppconverter includes providing an upconverter configured to suppress the carrier frequency and mirror image subcarrier frequencies of the lightwave, when upconverting the electrical signals onto the subcarrier frequencies.

10. The method of claim 7, wherein said providing first and second electrical signals includes providing first and second electrical signals at the same electrical frequency.

11. An optical transmission system comprising:

at least one optical receiver configured to receive an optical data signal; and,

at least one optical transmitter configured to transmit the optical signal to said at least one optical receiver via optical fiber, said at least one transmitter including

an upconverter having a first upconverter input and a second upconverter input, each input configured to receive at least first and second electrical data signals, said upconverter being configured to upconvert the at least first and second electrical data signals onto corresponding at least first and second subcarrier frequencies of a lightwave having a carrier frequency to produce the optical signal, wherein at least one of the corresponding subcarrier frequencies is greater than the carrier frequency and at least one of the corresponding subcarrier frequencies is less than the carrier frequency.

12. The system of claim 11, further comprising:

an electrical carrier source configured to provide first and second electrical carriers at the same frequency;

a first electrical modulator configured to modulate a first baseband signal onto the first electrical carrier to produce the first electrical data signal; and,

a second electrical modulator configured to modulate a second baseband signal onto the second electrical carrier to produce the second electrical data signal.

13. The system of claim 11, further comprising:

a first signal distorters configured to distort the first electrical data signal to compensate for chromatic dispersion of the optical data signal carrying data from the first electrical data signal; and,

a second signal distorters configured to distort the second electrical data signal to compensate for chromatic dispersion of an optical data signal carrying data from the second electrical data signal.

14. The apparatus of claim 13, further comprising:

a data encoder configured to encode and synchronize with a clock signal at least one of the electrical data signals and provide an encoded data signal; and,

a low pass shaping filter configured to shape the encoded electrical data signal, wherein, said signal distorter is further configured to separate the encoded electrical data signal into in-phase and quadrature phase components;

an electrical carrier source configured to provide an electrical carrier; and,

an IQ electrical modulator configured to modulate the in-phase and quadrature components of the electrical signal onto the electrical carrier and provide a distorted modulated electrical carrier to said optical upconverter, wherein said optical upconverter is configured to upconvert the distorted modulated electrical carrier onto the lightwave at a subcarrier frequency.

15. The apparatus of claim 13, wherein said signal distorter includes a group delay equalizer.

16. The system of claim 11, further comprising a polarizing element configured to orthogonally polarize the first subcarrier frequency relative to the second subcarrier frequency.

17. The system of claim 11, further comprising:

an optical splitter configured to split the lightwave into a plurality of split lightwaves at the carrier frequency;

a plurality of said upconverters corresponding to the split lightwaves and configured to impart electrical data signals carrying information onto the split lightwaves at different optical frequencies; and,

an optical combiner configured to recombine the split lightwaves into an optical data signal carrying the information on the different optical frequencies.

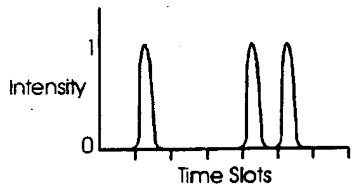


Fig. 1a

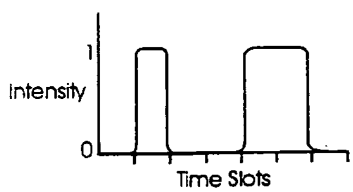


Fig. 1b

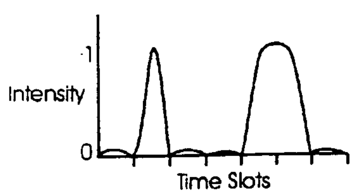


Fig. 1c

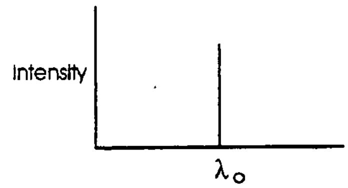


Fig. 2a

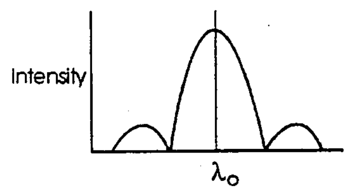


Fig. 2b

Fig. 2c

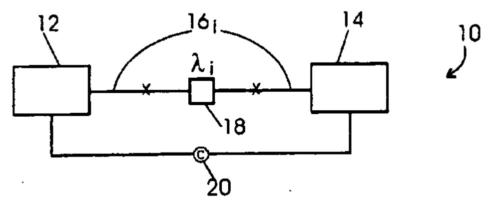


Fig. 3

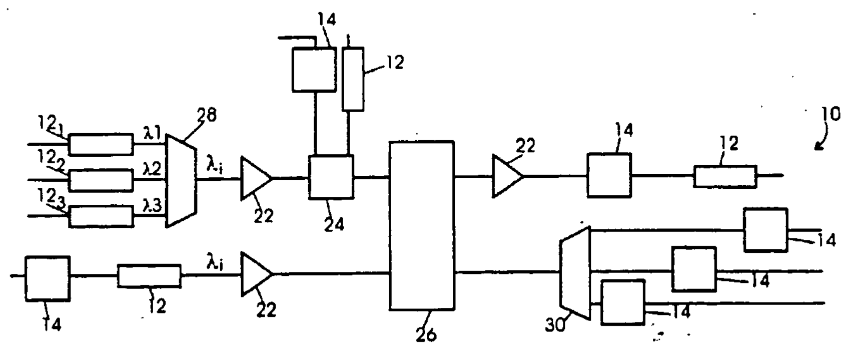


Fig. 4

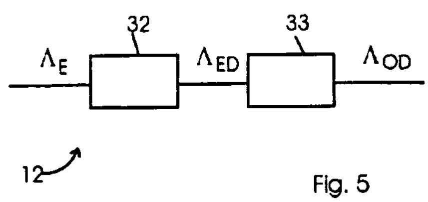


Fig. 5

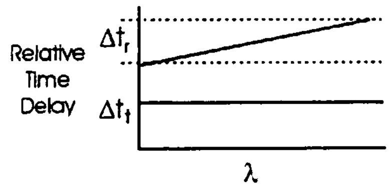


Fig. 6a

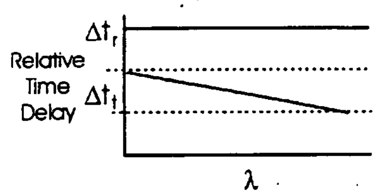


Fig. 6b

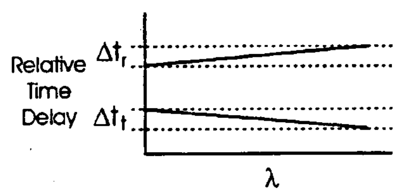


Fig. 6c

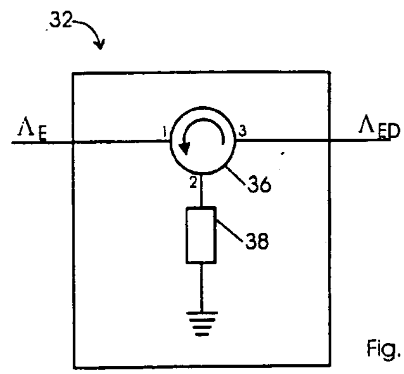


Fig. 7a

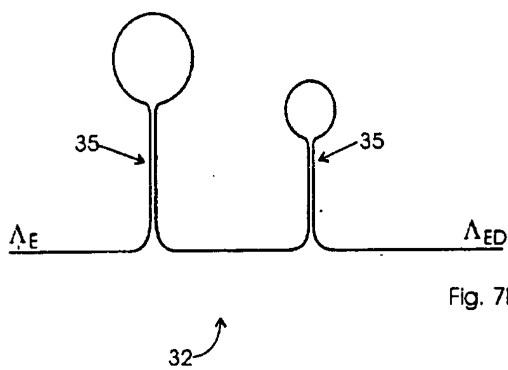


Fig. 7b

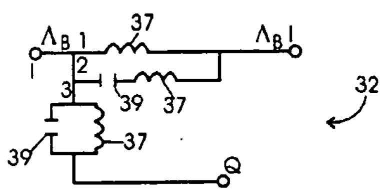
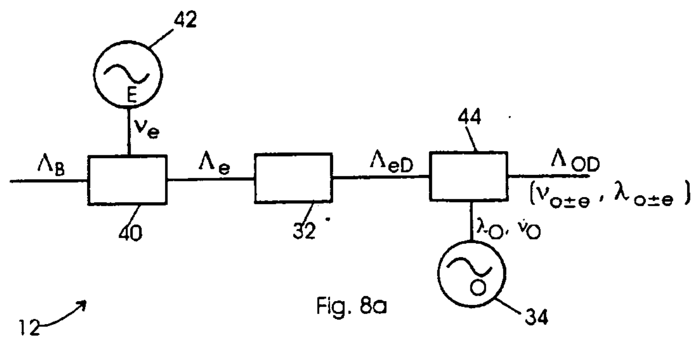
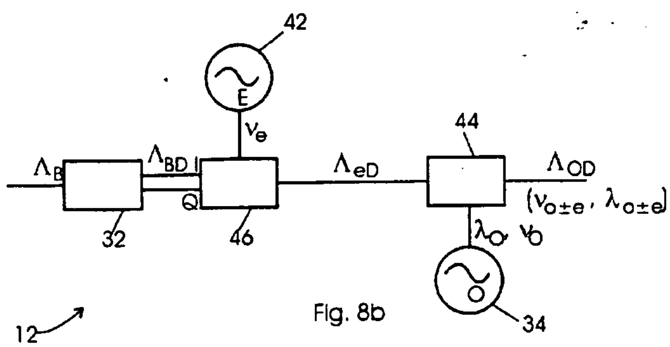


Fig. 7c



42
E
ν_e
Λ_B
Λ_e
Λ_{eD}
44
Λ_{OD}
$(\nu_{o\pm e}, \lambda_{o\pm e})$
40
32
λ_O, ν_O
O
34
12

Fig. 8a



42
E
ν_e
Λ_B
Λ_{BD} I
Q
Λ_{eD}
44
Λ_{OD}
$(\nu_{o\pm e}, \lambda_{o\pm e})$
32
46
λ_O, ν_O
O
34
12

Fig. 8b

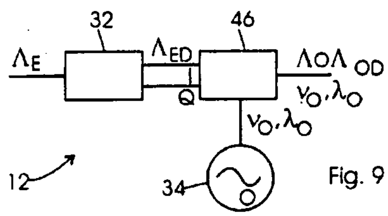

32
46
Λ_E
Λ_{ED}
Q
$\Lambda O \Lambda_{OD}$
ν_O, λ_O
ν_O, λ_O
12
34
O

Fig. 9

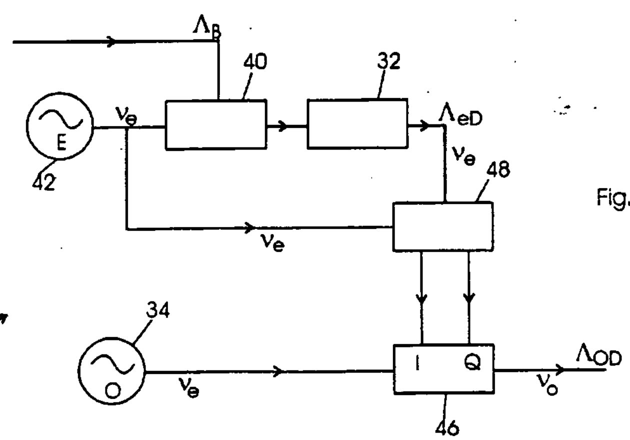
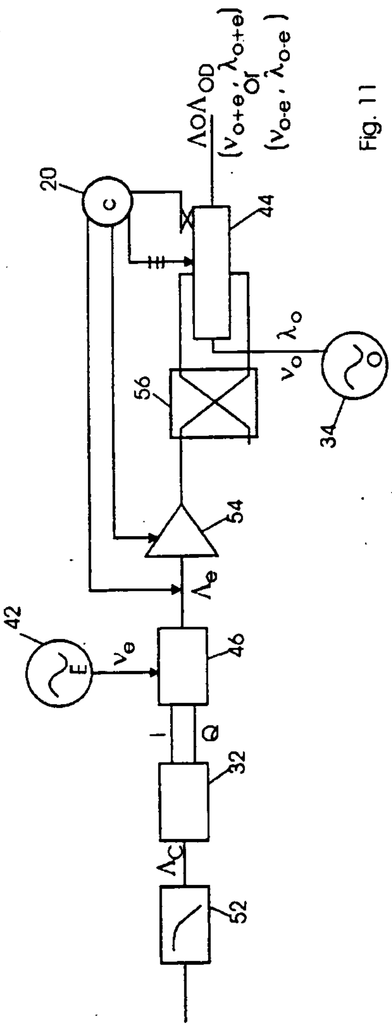

Λ_B
40
32
ν_e
Λ_{eD}
E
42
ν_e
48
ν_e
34
12
O
ν_e
I
Q
Λ_{OD}
ν_o
46

Fig. 10



20
C
44
ΛOΛOD
(νo+e, λo+e)
Or
(νo-e, λo-e)
νo λo
34
O
56
54
Λe
42
E
νe
46
I
Q
32
ΛC
52

Fig. 11

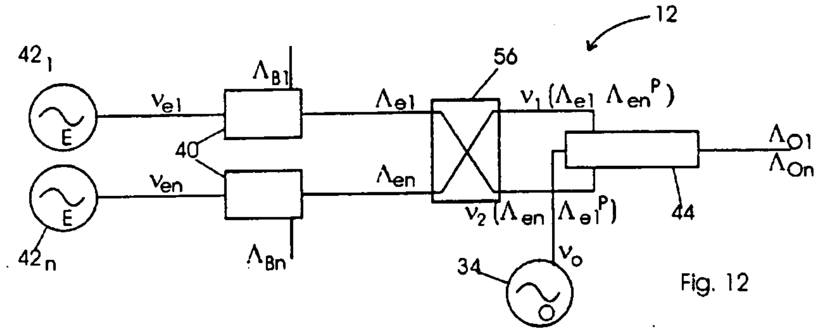

12
56
42_1
ν_{e1}
Λ_{B1}
Λ_{e1}
$\nu_1(\Lambda_{e1}\ \Lambda_{en}^P)$
40
ν_{en}
Λ_{en}
Λ_{O1}
Λ_{On}
E
E
$\nu_2(\Lambda_{en}\ \Lambda_{e1}^P)$
44
42_n
Λ_{Bn}
ν_o
34
O

Fig. 12

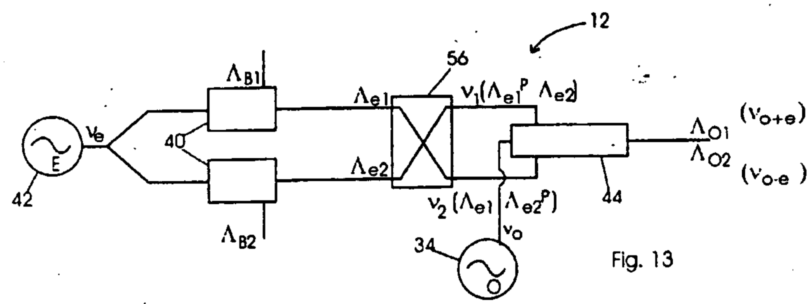
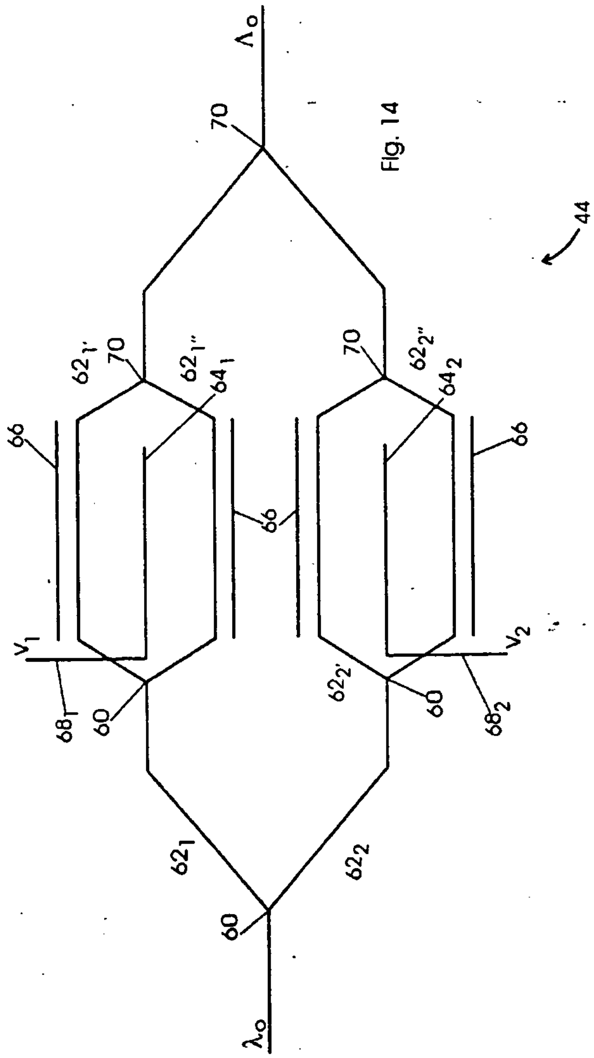
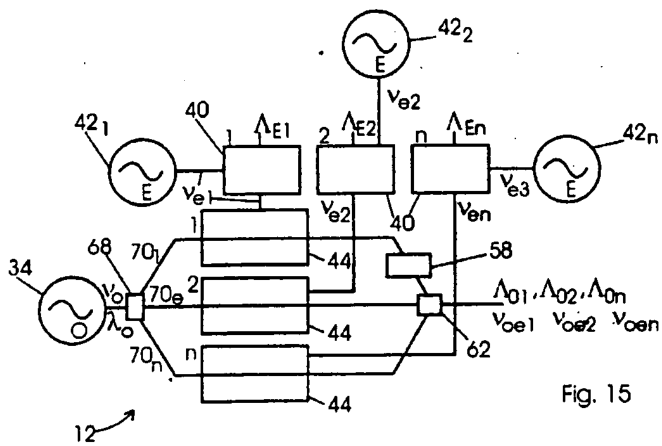

12
56
Λ_{B1}
Λ_{e1}
$\nu_1(\Lambda_{e1}^P\ \Lambda_{e2})$
ν_e
40
Λ_{O1}
(ν_{o+e})
Λ_{O2}
(ν_{o-e})
E
Λ_{e2}
42
$\nu_2(\Lambda_{e1}\ \Lambda_{e2}^P)$
44
Λ_{B2}
ν_o
34
O

Fig. 13



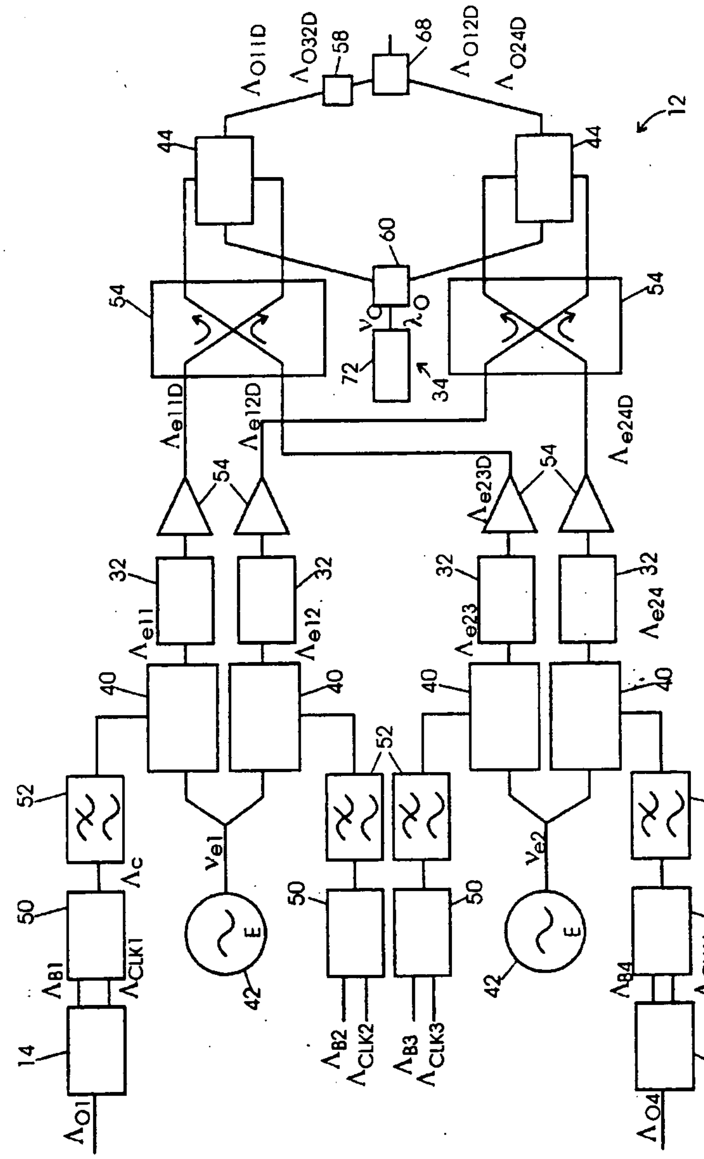
Λ_o
70
44
$62_{1'}$
$62_{1''}$
64_1
$62_{2''}$
64_2
66
V_1
V_2
68_1
68_2
60
$62_{2'}$
62_1
62_2
λ_o

Fig. 14



42_2
E
ν_{e2}
42_1
40
1
Λ_{E1}
2
Λ_{E2}
n
Λ_{En}
42_n
E
ν_{e1}
ν_{e2}
40
ν_{en}
ν_{e3}
E
1
58
34
68
70_1
44
ν_o
70_e
2
$\Lambda_{01}, \Lambda_{02}, \Lambda_{0n}$
ν_{oe1} ν_{oe2} ν_{oen}
O
λ_o
44
62
70_n
n
44
12

Fig. 15


12
14
50
52
40
32
54
44
58
60
68
72
34
42
E
Λ_{O1}
Λ_{O4}
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Λ_{CLK1}
Λ_{B2}
Λ_{CLK2}
Λ_{B3}
Λ_{CLK3}
Λ_{B4}
Λ_{CLK4}
Λ_c
ν_{e1}
ν_{e2}
Λ_{e11}
Λ_{e12}
Λ_{e23}
Λ_{e24}
Λ_{e11D}
Λ_{e12D}
Λ_{e23D}
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λ_O
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Λ_{O12D}
Λ_{O24D}

Fig. 16

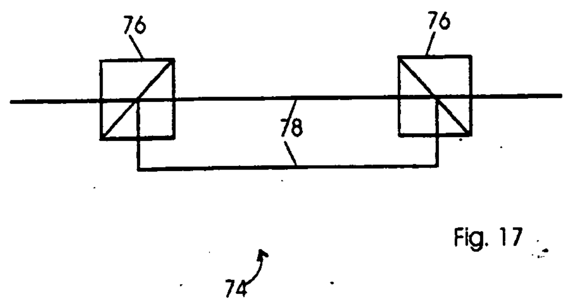

Fig. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/25885

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :IPC(6): H04B 10/04, 10/16; G02B 6/10
US CL : US: 359/181, 188; 385/3
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : US: 359/181, 188; 385/3

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST, WEST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, E	US 5,917,638 A (FRANCK et al) 29 June 1999, Fig. 16, col. 4, lines 32-67, col. 6, lines 56-67.	1-17
A	US 5,239,401 A (OLSHANSKY) 24 August 1993, Fig. 5, col. 6, lines 22-67, col. 7, lines 1-67.	1-17
A	US 5,101,450 A (OLSHANSKY) 31 March 1992, Fig. 5, lines 6, lines 44-67, col. 7, lines 1-67.	1-17
A	US 5,543,952 A (YONENAGA et al) 06 August 1996, Fig. 5, col. 5, lines 52-67, col. 6, lines 1-67.	1-17

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16 FEBRUARY 2000	02 MAR 2000

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